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# A Phreatic Explosion after AD 1663 at the Hiyoriyama Cryptodome, Kuttara Volcano, Southwestern Hokkaido, Japan

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Hiyoriyama is a Quaternary dacite cryptodome located in Kuttara Volcano, southwestern Hokkaido, Japan. The cryptodome is 350–550 m across and 130 m high, with an explosion crater at the summit. Here we report on a small-volume, phreatic fall deposit (the Hy-a deposit) erupted from the crater. The deposit consists mainly of fresh to altered, dacitic lithic clasts (up to 30 cm across) in a fine-grained matrix. The petrological features of the dacite are identical to those of rocks within the wall of the crater. The deposit increases in thickness and maximum grain size toward the crater, suggesting it was erupted from the crater. The Hy-a deposit overlies the Us-b tephra, which was deposited in AD 1663. The lithology, distribution, and stratigraphy of the Hy-a deposit suggest that a phreatic eruption occurred after AD 1663 at the summit of the cryptodome, resulting in formation of the crater.

**Key words**: phreatic eruption, explosion crater, Hiyoriyama Cryptodome, Noboribetsu Geothermal Field, Kuttara Volcano

## 1. Introduction

Hiyoriyama is a Quaternary dacite cryptodome located in the northern part of the Noboribetsu Geothermal Field, Kuttara Volcano, Hokkaido, Japan (Fig. 1). The cryptodome has a small explosion crater at the summit, suggesting that a minor eruption occurred during or after emplacement of the dome (Fig. 2). No previous study has investigated the timing of the eruption, and the formation age of the crater is unknown. This paper describes the distribution, lithology, and stratigraphy of a small-volume, phreatic fall deposit associated with the crater, and discusses the timing of the crater-forming eruption.

## 2. Hiyoriyama Cryptodome

The Hiyoriyama Cryptodome is located in the western part of Kuttara Volcano (Fig. 1). The volcano consists mainly of an andesitic stratovolcano (elevation, 549 m above sea level) with a small caldera at the summit (Lake Kuttara). The volcano evolved over the period 80–45 ka, involving early silicic explosive activity and subsequent stratovolcano building associated with caldera collapse at 40 ka (Katsui *et al.,* 1988; Yamagata, 1994; Moriizumi, 1998; Moriya, 2003). The Noboribetsu Geothermal Field is inferred to have formed after the collapse of the caldera (Katsui *et al.,* 1988). The geothermal field is approximately 1 km wide (northeast-southwest) and 1.5 km long (northwest-southeast).

The Hiyoriyama Cryptodome is elliptical in plan view, ranging in diameter from 350 m (northeast-southwest) to 550 m (northwest-southeast). It rises 130 m above the surrounding area, with the highest point being 377 m above sea level (Fig. 2A). The surface of the cryptodome is covered with sediments up to 15 m thick (Katsui *et al.,* 1988). Fission-track dating yields ages for the dome of 15±4 ka and 14±4 ka (Goto and Danhara, 2011). An explosion crater at the summit (Hiyoriyama Summit Crater; Fig. 2B) is 40×95 m in size (elongate northwest-southeast) and 20 m deep, and contains active fumaroles. The crater retains its primary morphological features, including the crater rim and crater wall.

The Hiyoriyama Cryptodome consists of coherent dacite that is well exposed in the crater wall. The dacite is grey and porphyritic, containing phenocrysts of plagioclase (<4 mm long, 21–25 vol.%), quartz (<5 mm, 6–8 vol.%), hypersthene (<2 mm, 4–6 vol.%), trace amounts of augite (<1 mm) and opaque minerals (<0.5 mm), and rare hornblende (<0.2 mm) (Fig. 3 A). The groundmass (62–66 vol.%) is granophyric, containing silica minerals, feldspars, and opaque minerals of <0.1 mm in size. Table 1 lists the whole-rock

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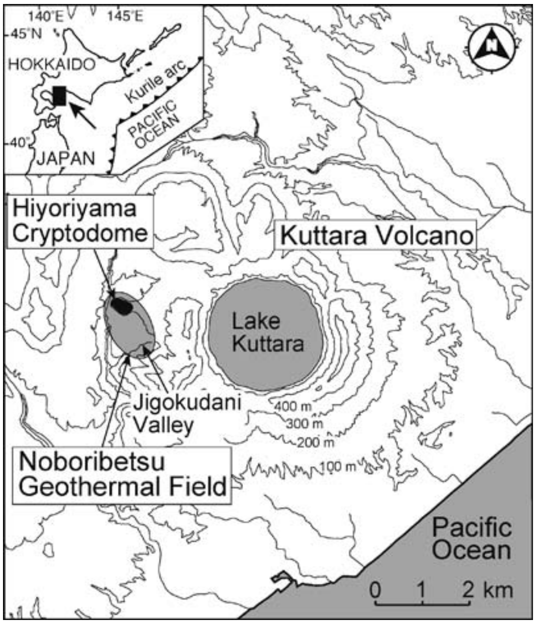


Fig. 1. Location of the Hiyoriyama Cryptodome in the Noboribetsu Geothermal Field, Kuttara Volcano, southwestern Hokkaido, Japan.

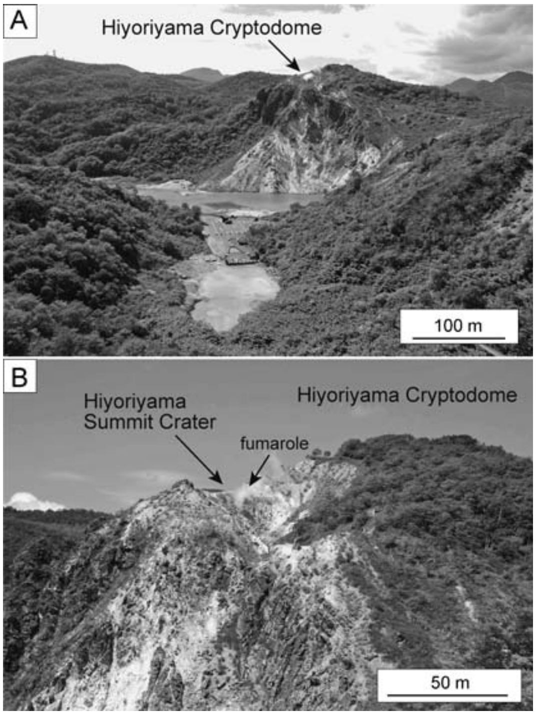


Fig. 2. Photographs of the Hiyoriyama Cryptodome. (A) The Hiyoriyama Cryptodome viewed from the southeast. (B) Explosion crater at the summit of the cryptodome (Hiyoriyama Summit Crater). Active fumaroles are present within the crater.

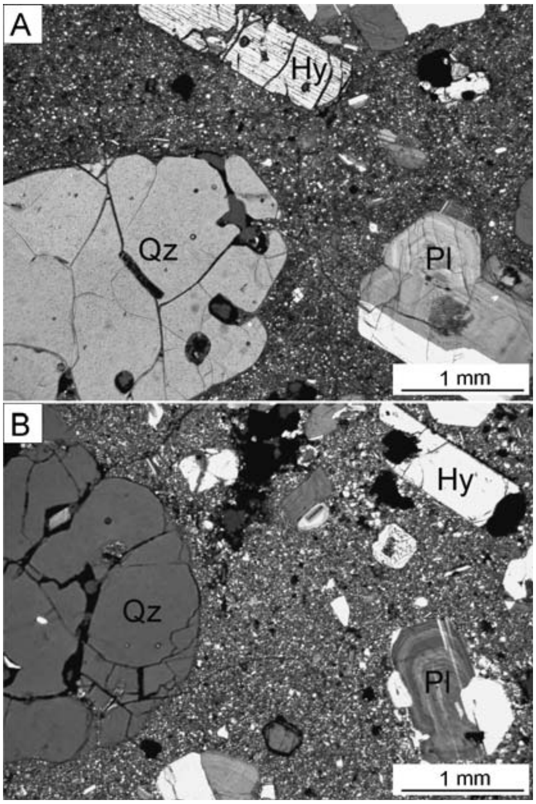


Fig. 3. Photomicrographs of dacite from the wall of the summit crater of the Hiyoriyama Cryptodome (A) and from the Hy-a deposit (B). Crossed nicols. Abbreviations: Qz, quartz; Pl, plagioclase; Hy, hypersthene.

major element chemical composition of the dacite (sample numbers Nb-83a and -83b), which contains 70 wt.% $SiO_2$, 3.5 wt.% $Na_2O$, and 1.5 wt.% $K_2O$.

## 3. Phreatic deposit

### 3–1 Nomenclature

The newly identified phreatic fall deposit occurs at the rim of the Hiyoriyama Summit Crater and in the adjacent area (Fig. 4). It occurs about 10 cm beneath the ground surface and was found within an excavated trench (Fig. 5). In this paper, the deposit is referred to as the 'Hiyoriyama-a phreatic deposit' (Hy-a deposit). The type locality of the deposit is on the northeastern rim of the crater. The Hy-a deposit differs from the Shinki-Jigokudani pyroclastic fall deposit reported by Katsui *et al.* (1988). The relation between these units is discussed below.

### 3–2 Description

The Hy-a deposit is pale brown, massive (nonstratified), matrix supported, poorly sorted, and com-

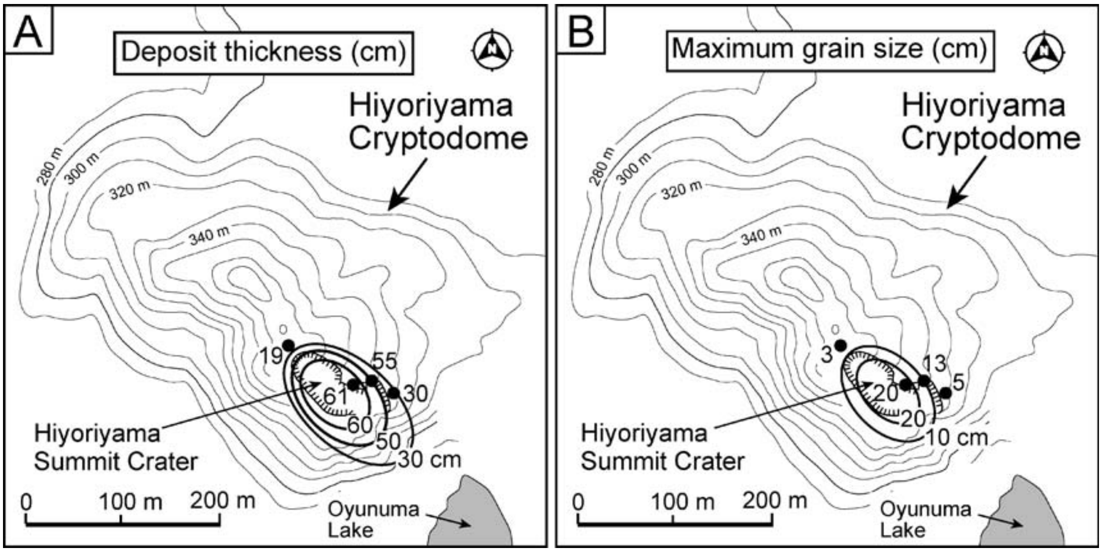


Fig. 4. Isopach map (A) and maximum-grain-size isopleth map (B) for the Hy-a deposit. The deposit occurs within ~100 m of the Hiyoriyama Summit Crater, and shows an increasing trend in thickness and maximum grain size toward the crater. The maximum grain size was calculated as the average long-axis diameter of the three largest lithic clasts. Contour interval is 10 m.

Table 1. Whole-rock major-element compositions of dacites from the Hiyoriyama Cryptodome (samples Nb-83a and -83b) and from the Hy-a deposit (Nb-79B, -80A, -80B, -80C, -81A, and -81B), as determined by X-ray fluorescence (Rigaku RIX-2000) at Shimane University, Japan, following the analytical method proposed by Kimura and Yamada (1996).

| | Hiyoriyama Cryptodome | | Hiyoriyama-a phreatic deposit (Hy-a) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample No. | Nb-83a | Nb-83b | Nb-79B | Nb-80A | Nb-80B | Nb-80C | Nb-81A | Nb-81B |
| $SiO_2$ (wt. %) | 70.05 | 69.80 | 70.03 | 69.69 | 69.82 | 69.58 | 69.74 | 69.84 |
| $TiO_2$ | 0.41 | 0.40 | 0.39 | 0.39 | 0.39 | 0.40 | 0.40 | 0.40 |
| $Al_2O_3$ | 15.29 | 15.59 | 15.03 | 14.92 | 14.96 | 15.05 | 15.03 | 15.08 |
| $Fe_2O_3$* | 4.42 | 4.38 | 4.33 | 4.72 | 4.55 | 4.68 | 4.55 | 4.55 |
| MnO | 0.09 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.09 |
| MgO | 1.07 | 1.08 | 1.05 | 1.03 | 1.11 | 1.09 | 1.09 | 1.07 |
| CaO | 3.83 | 4.02 | 3.81 | 3.98 | 4.11 | 4.05 | 4.14 | 3.87 |
| $Na_2O$ | 3.43 | 3.51 | 3.56 | 3.62 | 3.61 | 3.53 | 3.55 | 3.55 |
| $K_2O$ | 1.55 | 1.51 | 1.56 | 1.52 | 1.53 | 1.49 | 1.46 | 1.52 |
| $P_2O_5$ | 0.08 | 0.08 | 0.07 | 0.08 | 0.08 | 0.07 | 0.08 | 0.07 |
| Total | 100.22 | 100.46 | 99.92 | 100.04 | 100.26 | 100.04 | 100.14 | 100.04 |
| L.O.I. | 1.33 | 1.18 | 0.90 | 0.57 | 0.41 | 0.69 | 0.51 | 0.79 |

$Fe_2O_3$* = total iron as $Fe_2O_3$. L.O.I. = loss on ignition.

posed of subangular to subrounded lithic clasts (up to 30 cm across) in a fine-grained matrix (Fig. 5). The lithic clasts consist mainly of fresh to altered dacite, with minor altered andesite. No juvenile magmatic pyroclasts (fresh pumice, scoria, or volcanic glass) are observed.

The dacite is grey to brownish grey and porphyritic, containing phenocrysts of plagioclase (< 4 mm long, 22–24 vol.%), quartz (< 5 mm, 5–8 vol.%), hypersthene (< 2 mm, 4–7 vol.%), and trace amounts of augite (< 1 mm) and opaque minerals (< 0.5 mm) (Fig. 3B). The groundmass (63–65 vol.%) is granophyric, containing silica minerals, feldspars, and opaque minerals of < 0.1 mm in size. Table 1 lists the whole-rock major element chemical composition of the dacite (sample numbers Nb-79B, -80A, -80B, -80C, -81A, and -81B), which contains 70 wt.% $SiO_2$, 3.5–3.6 wt.% $Na_2O$, and 1.5 wt.% $K_2O$. The dacite in the Hy-a deposit is identical to the dacite lava exposed in the wall of the summit crater in terms of color, phenocryst assemblage, phenocryst size, modal abundance of phenocrysts, and chemical composition.

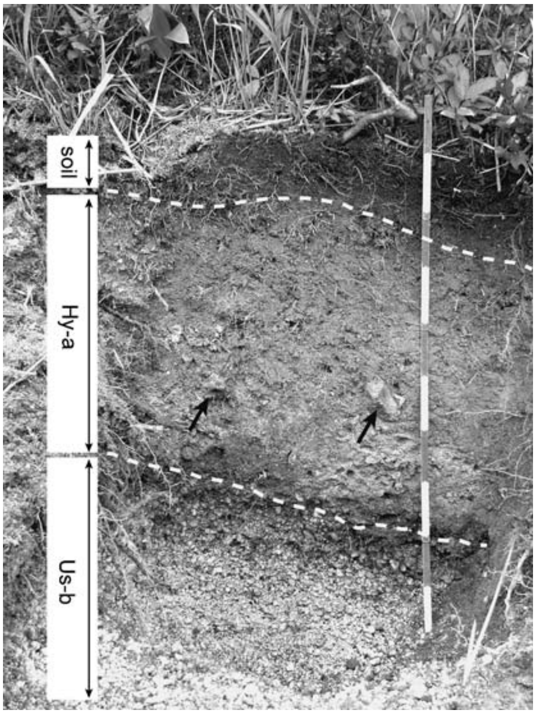


Fig. 5. Occurrence of the Hy-a deposit (Hy-a) at the northeastern rim of the Hiyoriyama Summit Crater (the type locality). The deposit consists mainly of dacitic lithic clasts (arrows) in a fine-grained matrix. The deposit overlies the Us-b tephra (Us-b), which was emplaced in 1663. Scale ruler is 1 m long (each colored segment is 10 cm).

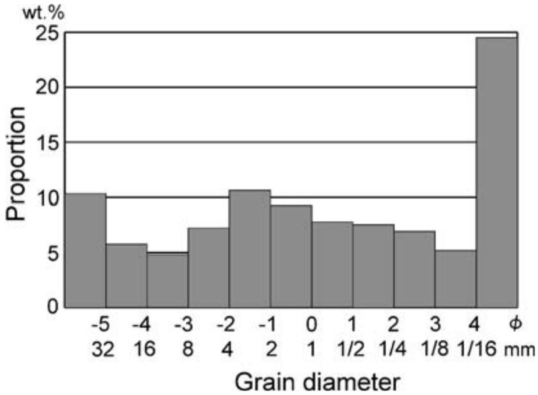


Fig. 6. Grain-size histogram of the Hy-a deposit, sampled from the northeastern rim of the Hiyoriyama Summit Crater (the type locality). The deposit has a polymodal grain-size distribution and contains a large proportion of grains less than 1/16 mm in size.

The matrix consists mainly of fresh to altered dacite and mineral fragments. The dacite fragments are petrologically identical to those present as lithic clasts. The mineral fragments consist of plagioclase, quartz, hypersthene, augite, and opaque minerals, all of which are components of the dacite. X-ray diffraction (XRD) analysis of the $< 2\mu$m fraction (as separated by hydraulic elutriation) revealed the presence of quartz, plagioclase, opal, alunite, pyrophyllite, and gypsum.

Figure 6 shows the grain-size distribution of the Hy-a deposit sampled from the northeastern rim of the Hiyoriyama Summit Crater. Because the matrix is cohesive, the sieving for grain-size analysis was performed in a water bath. The Hy-a deposit has a polymodal grain-size distribution and contains a high proportion of grains less than 1/16 mm in size.

### 3–3 Stratigraphy

The Hy-a deposit overlies a 60-cm-thick pumice fall deposit and is covered by a 10-cm-thick surface soil (Fig. 5). The pumice fall deposit is clast supported and poorly stratified, and consists of white to pale brown pumice clasts (1–3 cm in size). The pumice consists of fresh volcanic glass and crystals of plagioclase, hypersthene, augite, hornblende, opaque minerals, and apatite. The refractive index of volcanic glass ranges from 1.4887 to 1.4921 (mean, 1.4905; mode, 1.491; as determined by Kyoto Fission-Track Co. Ltd). The mineral assemblage, refractive index, and location of the deposit suggest that it is the Us-b tephra (Yokoyama *et al.,* 1973; Machida and Arai, 2003) derived from Usu volcano, southwestern Hokkaido. There is no palaeosol between the Hy-a deposit and the Us-b tephra, although a small amount of limonite is present.

### 3–4 Distribution and volume

Figure 4A and 4B shows the distributions of the thickness and maximum grain size of the Hy-a deposit. These data suggest that the deposit increases in thickness and maximum grain size toward the Hiyoriyama Summit Crater. The bulk volume of the deposit, calculated following Hayakawa (1985) using the 50-cm isopach, is $3.2 \times 10^4$ m$^3$.

## 4. Discussion

### 4–1 Origin of the Hy-a deposit

The distributions of the thickness and maximum grain size of the Hy-a deposit suggest it was erupted from the Hiyoriyama Summit Crater. The deposit consists of fresh to altered lithic clasts in a fine-grained matrix, and contains no juvenile magmatic pyroclasts, indicating it was produced during a phreatic explosion. The petrological features of the lithic clasts are identical to those of dacite in the wall of the explosion crater, indicating that the crater formed during the same eruption as that which produced the deposit. The volume of the deposit ($3.2\times10^4\,m^3$) is consistent with the geometry of the explosion crater (surface area, $40\times95\,m$; depth, 20 m; volume, $4\times10^4\,m^3$). The altered andesite lithic clasts may have originated from the overlying sediment of the cryptodome.

### 4–2 Age of the Hiyoriyama Summit Crater

The Hy-a deposit overlies the Us-b tephra, which is inferred to have been emplaced in AD 1663 (Yokoyama *et al.,* 1973), suggesting the Hy-a deposit was emplaced after this date. Hence, the phreatic explosion at the summit of the cryptodome must have occurred after AD 1663. The lack of soil development between the Hy-a deposit and the Us-b tephra indicates that the explosion occurred at some time between the late 17th and 19th centuries. This inference is consistent with the well-preserved morphology of the crater. We found no mention of the explosion in historical records; consequently, the date of the explosion remains poorly constrained. Considering the emplacement age of the Hiyoriyama Cryptodome (*ca.* 15 ka; Goto and Danhara, 2011), the phreatic explosion at the summit of the cryptodome occurred much later than emplacement of the dome. We suggest that the Hiyoriyama Cryptodome has an eruption history of dome emplacement at about 15 ka and a phreatic explosion at the summit after AD 1663. A similar eruption history has been reported for other silicic domes (e.g., Atosanupuri Dome, Hokkaido; Katsui *et al.,* 1986).

### 4–3 Relation between the Hy-a deposit and the Shinki-Jigokudani pyroclastic fall deposit

Katsui *et al.* (1988) reported a phreatic fall deposit (the Shinki-Jigokudani pyroclastic fall deposit) from the southern part of the Noboribetsu Geothermal Field. The deposit occurs above the Us-b tephra and consists of intensely altered, dacitic lithic clasts in a fine-grained matrix. The deposit increases in thickness toward the Jigokudani Valley, 750 m south of the Hiyoriyama Cryptodome (Fig. 1). Katsui *et al.* (1988) concluded that the deposit formed during a small phreatic explosion within the Jigokudani Valley after AD 1663. Our field survey found no evidence of the deposit on the Hiyoriyama Cryptodome.

The Hy-a deposit differs from the Shinki-Jigokudani pyroclastic fall deposit in terms of vent location (Hiyoriyama Summit Crater versus the Jigokudani Valley, respectively) and components (fresh to altered dacite versus intensely altered dacite, respectively). However, the two deposits occupy the same stratigraphic position (i.e., above the Us-b tephra) and may have been produced by the same volcanic activity. Therefore, we infer that the two deposits were produced by distinct phreatic explosions during an eruptive episode. Similar series of multiple-vent-forming phreatic explosions within an eruptive episode have been reported from Usu volcano, southwestern Hokkaido (e.g., the 1910 eruption: Yokoyama *et al.,* 1973; the 2000 eruption: Ui *et al.,* 2002).

The results of the present study will be of use in evaluating volcanic hazards within the Noboribetsu Geothermal Field.

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## References

Goto, Y. and Danhara, T. (2011) Zircon fission-track dating of the Hiyoriyama Cryptodome at Kuttara Volcano, southwestern Hokkaido, Japan. *Bull. Volcanol. Soc. Japan,* **56**, 19–23.

Hayakawa, Y. (1985) Pyroclastic geology of Towada volcano. *Bull. Earthq. Res. Inst.,* **60**, 507–592.

Katsui, Y., Yokoyama, I., Okada, H., Nishida, Y, Matsumoto, Y. and Kawakami, N. (1986) **Atosanupuri and Mashu (Kamuinupuri), its volcanic geology, history of eruption, present state of activity and prevention of disasters.** Committee for Prevention and Disasters of Hokkaido, Sapporo, 104p.

Katsui, Y., Yokoyama, I., Okada, H., Abiko, T. and Muto, H. (1988) **Kuttara (Hiyoriyama), its volcanic geology, history of eruption, present state of activity and prevention of disasters.** Committee for Prevention and Disasters of Hokkaido, Sapporo, 99p.

Kimura, J. and Yamada, Y. (1996) Evaluation of major and trace element XRF analyses using a flux to sample ratio of two to one glass beads. *Jour. Min., Pet. Econ. Geol.,* **91**, 62–72.

Machida, H. and Arai, F. (2003) **Atlas of Tephra in and around Japan.** University of Tokyo Press, Tokyo, 360p.

Moriizumi, M. (1998) The growth history of the Kuttara volcanic group. *Bull. Volcanol. Soc. Japan,* **43**, 95–111.

Moriya, I. (2003) Kuttara Volcano. In *Regional Geomorphology of the Japanese Islands, vol. 2, Geomorphology of Hokkaido* (Koaze T., Nogami, M., Ono, Y. and Hirakawa. K. eds.), 279–281, University of Tokyo Press, Tokyo.

Ui, T., Nakagawa, M., Inaba, C., Yoshimoto, M. and Geological Party, Joint Research Group for the Usu 2000 Eruption (2002) Sequence of the 2000 Eruption, Usu Volcano. *Bull. Volcanol. Soc. Japan,* **47**, 105–117.

Yamagata, K. (1994) Tephrochronological study on the Shikotsu and Kuttara Volcanoes in southwestern

Hokkaido, Japan. *J. Geogr.,* **103**, 268–285.
Yokoyama, I., Katsui, Y., Oba, Y. and Ehara, Y. (1973) **Usuzan, its volcanic geology, history of eruption, present state of activity and prevention of disasters.** Committee for Prevention and Disasters of Hokkaido, Sapporo, 254p.

(Edictional handling Mitsuhiro Yoshimoto)

# 北海道南西部クッタラ火山，日和山潜在ドームの山頂火口を形成した水蒸気爆発

後藤芳彦・佐々木央岳・鳥口能誠・畠山　信

北海道南西部クッタラ火山，日和山潜在ドームの山頂火口の周辺には，小規模な水蒸気爆発の堆積物（Hy-a）が分布する．この堆積物は，直径 30 cm 以下の新鮮〜変質したデイサイト質の石質岩片および細粒なマトリクスからなる．堆積物の層厚と最大粒径は山頂火口に向かって増大し，石質岩片は山頂火口の火口壁を構成する岩石と岩石学的な特徴が一致する．したがって，この堆積物は，日和山潜在ドームの山頂火口を形成した水蒸気爆発による噴出物であると考えられる．この堆積物は有珠山 b 降下軽石（Us-b）を覆うことから，山頂火口を形成した水蒸気爆発は 1663 年以降に起きたと考えられる．